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A COMPARATIVE SENSORY ANALYSIS OF HELEN KELLER AND LAURA BRIDGMAN

I. MECHANISMS UNDERLYING THE SENSORIUM *

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Several years ago, in an address to the American Neurological Association, I ventured the statement that the human race had not as yet developed more than a fifth of its potential brain power. With other evidence in support of this view, I[1] offered certain deductions based on the history and achievements of Helen Keller. Since that time, I have had the opportunity and privilege to study Miss Keller personally. It is now my purpose to assemble the results of this study in their fuller bearing on the potential development of the human brain and also to present a comparative sensory analysis of Helen Keller and Laura Bridgman. Such an analysis in itself must needs be a contribution to that partially written chapter in the annals of the sensorium which records the adaptive successes of the deaf and dumb and blind.

HEAD'S THEORY OF SENSIBILITY

Before I discuss Miss Keller's sensory organization, it seems desirable to consider certain theoretical postulates concerning the mechanisms underlying the sensorium as a whole.

The most convenient point of departure for such a consideration appears to be the theory of Henry Head and his collaborators, founded on their intensive studies of change in skin sensibility following division and suture of the cutaneous nerves. In consequence of this procedure, Head formulated the theory that there are two chief sense qualities in cutaneous sensibility; one component of this duality he called "protopathic" and the other "epicritic." This theory has been extensively discussed and has exerted widespread influence on all modern conceptions of sensation. In late years, no work in this field has appeared

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* From the Department of Neurology, Columbia University.

* Read at the Fifty-Fourth Annual Meeting of the American Neurological Association, Washington, D. C., May 1, 1928.

[1] The writer wishes to apologize for the frequent intrusion of the personal pronoun. On the other hand, this form of narration was purposely chosen for the reason that subject matter of this kind is readily converted into objectionable dogmatism if presented in more indirect discourse.

without giving conspicuous prominence to the theory of Head. It was necessary, therefore, for me to consider its general availability and pertinence in the studies undertaken to determine Miss Keller's sensory capacities. The theory accepted as intended by its author presents a broad generalization concerning the nature of sensation. It aims primarily to afford an evolutionary interpretation. Its principal conception is the distinction of two great sensory systems, classified as follows:

1. The "epicritic" system, which provides: for the recognition of light touch over hairless portions of the skin, or parts that have been freed of hairs; discrimination of intermediate degrees of temperature from about 25 to about 40 C.; localization of cutaneous impressions; discrimination of two compass points as two points; appreciation of differences in the size of the stimuli and mediation of all sensations by a mechanism which for the heat senses is not distributed in a punctiform manner, and which for pressure, although punctiform in that the most sensitive spots lie over the hair bulbs, is yet of a different kind from the punctiform organs for protopathic warmth, cold and pain.

2. The "protopathic" system, which provides: for sensation of cutaneous pain by pricking, burning, freezing, electric stimulation or plucking the hairs; the hair sensibility, which is a composite of tingling or formication that comes from stimulating the hairs; the sensation of heat above 45 C.; sensation of cold below 20 C. All of these sensations are intense, with more diffuse and vehement reactions than occur in normal sensibility. These sensations, moreover, have in general a disagreeable or uncomfortable quality.

The capacity of localization in all qualities of "protopathic" sensibility is perverted, in that sensations radiate widely, are diffuse or else are referred remotely. "Protopathic" sensations are mediated by mechanisms which are distributed throughout the skin in a punctiform manner. Normally, these two systems of the skin function together—they supplement one another, and also have certain reciprocal relations as a result of which the "epicritic" system has an inhibitory effect on the "protopathic" system. Further, the latter system in general serves for the transmission of intense sensations which are only poorly localized, while the "epicritic" modifies this faulty localization and corrects it by partially inhibiting "protopathic" intensity and adding its own complements to sensation.

The evolutionary implication in Head's theory, however attractive and useful it may be as a generalization, does not receive the full support of known facts. If, as the theory presumes, "protopathic" sensation was the essential forerunner of later developments in the sensorium, the direct results of which were the further advancement of discriminative qualities in sensation, there are relatively few facts to support this view. Unquestionably, the "protopathic" sensation is inherently protective in its projicience. It depends on a widely radiating afferent inflow and a correspondingly diffuse efferent output. Its natural results tend to be mass reactions, distinctly unlike the discrete response determined by the "epicritic" inflow and its definitely discriminative projicience.

To consider these two components in any sense temporally independent or even objectively distinct would seem to contradict the very ends toward which animal organization directs its efforts. Certainly it would be difficult to conceive of any form of animal life, however low and simple its plan of organization, which could rely solely on a "protopathic" sensory equipment. Such an equipment, which would be inherently protective and implicit to a defense mechanism, would nevertheless be without the simultaneous operation of a directing sensory equipment to guide its efforts and make them adequately effective. One of these sensory components would be useless without the other, and it is equally true that no animal form exists in which the play of both of these sensory elements may not be readily discerned in all of its behavior. It seems clear in this light that any such priority in the evolutionary sense of a specific sensory quality is entirely out of the question. Furthermore, there seems little reason to draw any hard and fast boundary between two such presumptive types of sensation, since an intimate degree of mutuality and interchangeability actually exists between what is called "protopathic" and "epicritic." Any decisive cleavage between the two would seem impossible. Indeed, when such cleavage is made, it serves more the conveniences of nomenclature than the classification of known facts. This is all the more obvious when the very qualities of sensation which at one stage of development, either ontogenetic or phylogenetic, may be termed "protopathic" at a subsequent period show the characteristics of "epicritic" projicience.

Nor is the objection to this distinction founded alone on its failure to make a decisive and clearly defined contribution in the evolutionary sense. This interpretation seems to overlook well recognized clinical facts, facts indeed of common experience, which make clear that certain types of avowedly "protopathic" sensation may and often do rise to "epicritic" levels.

To maintain, therefore, that such sensory stimuli as pin-pricking, burning, freezing, electric irritation, plucking out of the hairs, or temperature above 45 C. and below 20 C., do not have discriminative qualities, seems wholly untenable. In the first place, some degree of discrimination or of localization adds an "epicritic" complement to all of these sensory impressions. In the second place, there is undeniably discrimination in the degree of discomfort caused by plucking out of a hair under different conditions; for example, the pain experienced in pulling out a hair from a normal hair follicle and from a follicle that is infected. The incision of an infected finger as compared with a similar incision of a noninfected finger also reveals discriminative differences. Both the degree of discomfort and the localization of the pain imply "epicritic" activities associated with these painful stimuli. The theory which deprives pain sensibility of actual discriminative qualities cannot be valid in the light of common experience. This type of sensation may not possess the full range of "epicritic" associations inherent in the more highly discriminative sense of touch, but it does manifest so much of these qualifications as to deserve some place, however low, among the sensory qualities endowed with definite discrimination.

Head's theory of sensation, as Boring pointed out, may have its definite usefulness as applied to certain pathologic conditions, but beyond this it does not seem to have any real application. And yet there seems grave doubt to me whether this theory has justification even under pathologic conditions. How much of difference between his two types of sensation may be attributed to metabolic changes due to nerve cutting and regeneration must remain a question. The proposed distinctions may be based on phenomena of the traumatic procedure of operative intervention with the nerve and adjacent tissue. Furthermore, this distinction of "epicritic" and "protopathic" cannot be applied in testing the normal person, since, as Head clearly showed, there is only one place in the human body in which "protopathic" sensation exists, namely, in the glans penis. Thus, in the examination of normal persons, Head's distinction would be valid only in such a limited area as to make it of no value for purposes of sensory study.

Casting still further doubt on the validity of the theory which has brought into vogue the use of the terms "epicritic" and "protopathic" are the observations of certain investigators who have repeated Head's procedure of research and have been unable either to confirm his results or to bring themselves into agreement with his conclusions. Trotter and Davies, in many points, rejected Head's hypothesis, while Boring was more emphatic even than they in his refusal to accept it. Boring maintained that Head's subdivision of cutaneous sensibility into "protopathic" and "epicritic" is open to criticism not only because it is inconsistent in its evolutionary aspect with the hypothesis of the development of other modes of sensation but because it cannot replace other hypotheses of cutaneous sensibility since it is applicable only to a particular group of facts; also because it is not sufficiently thorough-going to constitute a true theoretical formulation; and finally, because it indicates generalities which admit of exceptions or are of doubtful nature.

It is for the reasons already cited that the terms "epicritic" and "protopathic" have been omitted from the sensory studies of Helen Keller. It seemed but fair, however, to discuss the reasons why they have been omitted.

More recent studies dealing with the nature of perception by Sir John Herbert Parsons maintain that the criticisms of Head's hypothesis do not invalidate the theory of the dual mechanism of sensation. Parsons has modified the theory by introducing a "dyscritic" mechanism on which an "epicritic" is superposed. At a still higher level he would introduce a "syncritic" mechanism subserved by the cerebral cortex and having the function of integrating "epicritic" phenomena. It is not clear that Parsons has done other than complicate an already overcomplex situation. The addition of these several new synthetic terms as recommended by him may be of great service for the purpose of graphic discourse, but there is little assurance that they offer any real assistance in the further interpretation of the facts. He did, however, recognize a cognitive element in the crude "protopathic," and this he preferred to call "dyscritic." As he would have it, the two components in the dual sensory system are, first, the "protopathic," now called "dyscritic," which is of vital import, and second, the "epicritic," of cognitive import. Applying these "dyscritic" and "epicritic" components to vision, as he would to all forms of somatic sensation, Parsons admitted that "dyscritic" vision has lost some of the characteristics of primitive "protopathic" sensibility and appears to have gained some "epicritic" characters in its manifestations in normal man. Moreover, it is not improbable that "dyscritic" vision may, under certain conditions, show some qualitative differentiations of "epicritic" vision. This admitted merging of one form of sensation into the other seems to make the fact obvious that the recognition of these two categories in the presumed dualism of sensory mechanism establishes a distinction without a difference.

Perhaps a more useful and certainly a much simpler form of nomenclature as applied to the sensations was that suggested by Kappers in his terms "vital" and "gnostic." Yet, as an interpretation of the phenomena involved in sensation, particularly as applied to cutaneous sensation, Boring's theoretical proposal seems to be most profound and comprehensive. In this proposal, he accepted the general principles of Bernstein's theory. This theory supposes that afferent nerves originating in adjacent regions of the skin through their functional actions are projected on adjacent regions of the sensorial nervous system. This is the principle of central projection. The theory also holds that the nervous impulse, while most effective at the point of its central projection, tends to spread to adjacent central regions. This is the principle of central diffusion. Boring concluded:

> The hypothesis more satisfactory than that of Head is one which assumes that single sensory spots are innervated by more than one nerve fiber; that this multiple innervation if projected upon the central nervous system as multiple excitations, multiple innervations, may furthermore be effective as summation or as inhibition of the excitations involved.

But in spite of the really stimulating influence of all of these theories concerning the nature of sensation, it must be admitted that they are all mere postulates based on a more or less adequately systematized introspection. The actual and measurable control of the factors entering into the processes of sensation extends but a short distance inward from the receptors and the receptor surfaces. Anything more than inference concerning the nature of these processes in the central nervous system is still beyond one's reach. And thus one theory may be as pleasing as another.

Boring's theoretical proposal, based on Bernstein's conception of the projection of adjacent cutaneous areas on adjacent regions of the cerebral cortex, although it disposes most effectually of the presumed dual mechanism of Head's theory, is none the less an admitted postulate which has not been proved by actual demonstration and which, as far as may be seen at present, is not susceptible of such proof. As for Head's dualistic conception of sensation, no recommendation may be made for its value in the study of sensation under normal conditions. Parsons' more recent modification of sensory dualism is an attractive and, to me, an alluring postulate. His "dyscritic" optic thalamus and "epicritic" cerebral cortex fit with such disquieting perfection into the diagrammatic schemas of sensory organization, as I long have hoped they might, that this very element of wish fulfilment makes me all the more skeptical of their validity!

It is undeniable, therefore, as Adrian contended in his recent communication, "The Basis of Sensation," that "there is an unsatisfactory gap between two such events as the sticking of a pin into my finger and the appearance of a sensation of pain in my consciousness. Part of the gap is obviously made up of events in my sensory nerves and brain and the psychological method by itself can tell me nothing at all about these two events." Adrian undertook to measure the passage of impulses conducted by sensory nerves. This proved to be possible because electric effects do occur in such nerves on stimulation of their end-organs. For estimating the passage of impulses along sensory nerves, Adrian employed the cathode ray tube in combination with a capillary electrometer and a three or four valve amplifier. By this means, he was able to detect action currents in nerve fibers leading from sense organs. Records were made of the discharge of sensory impulses produced by tension on a muscle, pressure, touch, movement of hairs, and pricking with a needle. In this manner sensory impulses, as they pass inward over a sensory nerve fiber, have been measured in their rate, intensity and rhythm, and also in regard to other functional aspects. Thus far one may trace the sensory nerve impulses with measurable certainty, but beyond this is still the expansive terra incognita into which they enter to form sensations the constitution of which it is not yet possible to estimate or evaluate by any metrical or demonstrative method.

THE NATURE OF SENSATION

Whatever may be the objections to the several hypotheses concerning the nature of sensation, clinically it is not difficult to discern the general characteristics of discriminative sensibility which represents the assemblage of those sensory impressions having as their ultimate object the production of discretion and judgment.

In contrast to the qualities of discriminative sensibility are those sensory elements which go to make up affective sensibility. These are equally obvious. The latter portion of the sensorium enters into the various gradations of feeling tone. The impressions composing it produce changes in the general affect, altering it either favorably or unfavorably. But this more clinically practical conception of the sensorium also takes a too limited attitude toward the entire question of sensation. In fact, because it does leave the entire subject as a matter of sensation, it seems to miss the broadest biologic significance of the sensorium. Sensation as such might be regarded as a relatively negligible quality in the living organism, if it were not for the reactive turnover or effector responses which arise out of the senses. To leave the impressions from the outer world—by whatever avenue of approach they may have reached the nervous system—purely in the form of sensation overlooks entirely that conversion of energy for which the nervous system is primordially constructed.

It may be asked of what service would be the impression of sight, hearing, touch or pain, if it remained in the sensation phase and if it did not activate, direct or control some response or sequence of responses which had bearing on the process of living. Indeed, the entire realm of sensation justifies itself only if it is productive of adequate reactions. In this light, when the goal of sensation is regarded as reaction, the full biologic significance of all the impressions which enter the sensorium may be properly appreciated.

That modality long known as discriminative sensibility takes on the full dignity of its biologic importance when all impressions pertaining to it appear to have an inherently directive or guiding influence in the production of reaction. What is seen, no longer remains vision but is vision transformed into the productive and guiding effects of animal behavior. The same also is true of hearing which no longer occupies the physiologic aloofness of mere sensation, but becomes incorporated as a directing influence in the behavioral reactions of the animal. What is true of sight and hearing is also true of taste and smell, as it is likewise true of touch, pressure, temperature and vibration.

Thus, while it is possible to accept and recognize the accredited categories of discriminative and affective sensibility with certain critical reservations, these two sensory components seem to be vitalized and made thoroughly dynamic by attributing to the former an inherently directive or guiding influence in reaction, and to the latter an equally inherent protective or guarding influence. The inherently directive influence of discriminative projicience is a primary and essential but not an exclusive quality of this type of sensibility. So, likewise, the protective quality in affective sensibility is both primary and essential but not exclusive. Either of these sensory modalities may under certain conditions operate in a protective or a directive capacity.

Considered, then, from a simple and objective point of view, the energy turnover which results in directive projicience depends on an afferent stream of impulses from the total environment, of which there are two major subdivisions: (1) body environment and (2) mundane environment.

According to this view, the nervous system is directly surrounded by the rest of the body and less directly by the outside world. The afferent flow from the body environment is composed of skeletal, muscular and visceral impulses, while from the mundane environment this inflow consists of impulses derived from physical and chemical contacts.

The visceral impulses from the body have not been investigated in this study and are included here merely for the sake of completeness in evaluating the total environment. The skeletal and muscular component of body sense, on the other hand, comprises two extremely important senses or sensory pathways, namely: (1) the muscle, bone, joint, tendon sense, and (2) the vestibular sense the end-organs of which are in the semicircular canals, utricle and saccule.

Sherrington proposed to call these two senses collectively the "proprioceptive" sense. Some objections may be urged against this term, especially since visceral sense is also definitely proprioceptive. It has seemed to me more direct and convenient to speak of those sensory elements pertaining to the muscles, bones and vestibular apparatus as the posture-motion sense. The chief sources of stimulation for the sensory inflow from these parts of the body are motion and posture. It is not difficult to appreciate the manner in which such impulses serve to direct the actions of the body.

Stimuli from the outside world contribute to the formation of the contact senses. This distinction permits of the following classification:

1. Chemical Contact Senses
    - (*a*) Smell
    - (*b*) Taste
2. Physical Contact Senses
    - (*a*) Touch
    - (*b*) Pressure
    - (*c*) Vibration
    - (*d*) Temperature
3. Distance Contact Senses
    - (*a*) Sight
    - (*b*) Hearing

The physical and chemical contact senses depend on stimuli which materially touch the body surfaces. The distance contact senses have their source of stimulation more or less distant from the body, and touch certain areas of it through the mediation of waves of light or of sound. It is probable that waves of other kinds touch the body, but this question opens a new field for speculation and research.

The necessity of sensations of sight, hearing, taste, smell, touch, pressure, temperature, vibration, motion and posture for guiding the actions of animals is easily appreciated from any study of vertebrate behavior. The service of such senses is therefore essentially and primarily directive.

The body and contact senses having a directive significance may be grouped as follows:

Body Sensibility

I. Posture-motion sense
  1. Motion sense
  2. Posture sense
  3. Balance sense

Contact Sensibility

I. (*A*) Physical contact senses
  1. Touch sense
  2. Pressure sense
  3. Vibratory sense
  4. Temperature sense
 (*B*) Chemical contact senses
  1. Smell sense
  2. Taste sense

II. Distance contact senses
  1. Sight
  2. Hearing

Distinctions in this classification are based on the various types of stimuli adequate to the several different sensory components. In this, as in most attempts to be categorical, there are difficulties and objections. For example, all forms of contact stimuli touch the body immediately. Intermediacy is in reality figurative in that it indicates a source of stimulation more or less remote from the body, the stimuli from which require some medium such as light or sound waves to reach the receptors. For this reason, Sherrington distinguished between contact and distance receptors.

The sense of smell is another instance of difficulty in classification, for although the sense actually depends on a chemical relation between the olfactory receptors and the volatile stimuli, the source of the latter may be at a long distance from the body. Again, temperature sense may be stimulated by immediate contact with the body or by a source of heat at a considerable distance from the receptors.

Running through each of the components of sensation is a specific sensory quality which is essentially and primarily protective rather than directive. This quality is easily recognized in common experience. The stimuli which produce it are usually called "harmful." They cause distress, discomfort or some feeling foreign to the normal sense of well being. They act as threats, warnings or signals of actual danger to the tissues of the body. Carried to extremes, they often become painful, but more often fail to reach this level of distress and produce a sense of annoyance only. The range of these stimuli embraces all degrees of discomfort from such actual pain to these slight annoyances, but the constant result of the energy turnover caused by them is some protective or guarding reaction. This sensory quality pervades all varieties of body and contact sense. It may be easily discerned in motion, posture and balance senses, as when joints are overflexed or overextended, or when extreme postures in limbs are too long maintained or the vestibular apparatus is overstimulated. It is developed by contact with extremes of heat or cold, sharp or rough surfaces, and by the application of severe pressure and heavy vibration. It also results from drastic chemical stimulation of taste and smell as well as from too great intensity of light or sound. It is proposed to designate this sense quality as the "harm" or "hurt" sense because its special import is either harmful or hurtful, and its reactive response is clearly protective. Numerous objections may properly be urged against the term, and I suggest its use only as a convenient expression until a better one is devised to embrace the observations resulting from certain sensory tests applied in this study.

A COMPARATIVE SENSORY ANALYSIS OF HELEN KELLER AND LAURA BRIDGMAN

II. ITS BEARING ON THE FURTHER DEVELOPMENT OF THE HUMAN BRAIN *

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It was my special problem in considering Helen Keller's sensory equipment to estimate as accurately as possible the value of the several senses contributing to her sensorium by which she gained an impression of her total environment. From her nineteenth month, she was blind and deaf. Her sense of smell, however, has been preserved and is of actual value to her in making contacts with the world. Her sense of taste is likewise preserved; it is, however, of much less value than the sense of smell but has not been without its benefits in her development. Being totally deprived of her visual and auditory senses, she depends primarily on her sense of touch.

A comparison between Helen Keller and Laura Bridgman has important bearing. Miss Bridgman was even more limited as to her sensory avenues than Miss Keller. She lived to be about 60 years of age. During infancy she suffered from severe convulsions. In her twenty-fourth month she had scarlet fever. Two older sisters died of the disease. Laura's eyes and ears suppurated, and sight as well as hearing was destroyed. Smell and taste were so nearly destroyed that both of these were almost useless to her during the greater part of her life. It is questionable whether at any time she had olfactory sense. Thus, Laura Bridgman made her adjustment to life with but one of the principal contact senses, namely, the sense of touch. Helen Keller, on the contrary, had the advantage of olfactory sensation and also somewhat of the sense of taste. The latter sensory avenue failed to open up much of the world to Miss Keller, but the sense of smell has proved to be of considerable importance in her intellectual development.

A brief history will suffice to establish Miss Keller's clinical background.

She was born, June 27, 1880, in Tuscumbia, a little town of northern Alabama. Her father's ancestry was Swiss. One of these Swiss ancestors was the first teacher of the deaf in Zurich and wrote a book on the subject of their education.

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Her mother was an Everett, belonging to the same family of Everetts as Edward Everett and Edward Everett Hale.

She was born healthy and remained so until in her nineteenth month, when she suffered from what was called "an acute congestion of the stomach and brain" which deprived her of sight and hearing. She had learned to say a few words, but these were soon entirely forgotten. And so as a result of her illness she became deaf, blind and dumb. When she was 6 years old, Dr. Alexander Graham Bell advised her father to write to the Perkins Institute for the Blind, in Boston, and ask for a competent teacher. In March, 1887, Miss Sullivan, now Mrs. Macy, came to Helen, in the beginning of her seventh year. Of this momentous event, Miss Keller writes: "Thus I came out of Egypt and stood before Sinai and a power divine touched my spirit and gave it light so that I beheld many wonders, and from the sacred mountain I heard a voice which said 'Knowledge is love and light and vision.'"

The truly marvelous results of education which Miss Keller has now made a matter of history were due to the ingenuity and wisdom of her teacher. Mrs. Macy, under whose tutelage she prepared for and entered Radcliffe College in the fall of 1900. She graduated with honors, and since that time her writings, her addresses and her efforts in behalf of those afflicted as she has been are among the notable achievements of modern civilization.

ANALYSIS OF HELEN KELLER'S SENSORY EQUIPMENT

To evaluate Miss Keller's sensory equipment, it is necessary to discuss each one of her senses separately. This discussion has as its main object a comparative study with presumably normal adults of approximately the same age as Miss Keller. For the purpose of making such comparison, it was necessary to establish certain means for measuring sensation in order that the measurements in the normal group might be compared with those of Miss Keller. In consequence, it was thought advisable to devise certain new instruments or to provide the application of certain modes of sensory stimulation, the degree of intensity or volume of which was measurable.

So far as possible, the tests applied in this study were metrical, and the figures obtained as a result of such measurements were made the basis of comparison. In dealing with each sensory component, two aspects of its sensory avenue were considered: (1) what may be called the subjective phase, or what the subject reports concerning this sense irrespective of the application of any tests, and (2) the objective phase, revealing what the subject reports as a result of special tests devised to stimulate this sensory pathway.

The Sense of Smell.—Beginning with Miss Keller's olfactory sense, the anatomic substratum of which is the first or olfactory cranial nerve, with its territories in the brain making up the rhinencephalon, the following facts have been brought to light: Miss Keller has an extremely sensitive olfactory sense. I may recite in this connection my experience with her in a drive from her home in Forest Hills to Garden City, a distance of about twenty miles. The windows of the car were open. It was a fresh, crisp day in winter. I asked Miss Helen if she could tell me anything about the country through which we were passing, and her first observation was that we were then making our way through open fields. This proved to be the case, for the road ran through a golf course. Later, she said that we were passing trees. The road at this point made its way through a small grove. She then called attention to the fact that we had just passed a house with an open fire, and looking back I saw a small cottage with smoke pouring out of its chimney. She recognized at once when we turned off the main road to enter the Motor Parkway, and in the course of our drive along this road she declared that we were then passing a number of large buildings; looking behind me, I saw that we were actually in the vicinity of the several groups of structures constituting the Creedmore State Hospital for the Insane. In the course of our conversation concerning her olfactory sensitiveness, I asked Miss Keller if she would write out for me how important the sense of smell had been to her life and development. Shortly after this Miss Keller called attention to the fact that we had just entered Garden City and were passing the plant of Doubleday and Doran, her publishers, which actually was the case. Her realization of this fact, she told me, was due to her olfactory recognition of the ink from the presses of this publishing establishment with which she was familiar. In response to my request for some statement concerning her olfactory sense, Miss Keller wrote on the typewriter the following letter addressed to me, which is transcribed in full, not only as bearing on the point in question, but as showing the remarkable content of Miss Keller's mind, her literary appreciation, her phenomenal memory and her mastery of literature.

Forest Hills, L. I., N. Y., Feb. 8, 1928.

Dear Dr. Tilney:—Since our conversation last Saturday with regard to the importance of odors and vibrations in my life, I have remembered that I went into it quite fully in "The World I Live In." I asked Mrs. Henney to send you the book. You probably have it by now.

The sense of smell is the esthetic sense, I think, even more than sight. I know that odors give me a vivid conception of my surroundings. I call smell my landscape because, when I walk or drive through the country, so many odors tell me of fields, streams, honey-sweet valleys and hillsides covered with pines. If, as we are told, the ten thousand Greeks "shouted for joy when they saw the sea," I can imagine there must have been still more rejoicing when its bracing breath filled their nostrils.

How many memories, sad and bright, odors awaken in one's heart! Instantly a scent will carry one back through the years to a forgotten experience. A correspondent who had been with the "Princess Pat's Regiment" in France told me that once, after his return to America, the scent of trodden grass caused him to faint, so forcibly had it brought to him the memory of being wounded, and lying with face downward on blood-soaked grass!

I am very sensitive to unpleasant odors. They have a depressing influence upon me: for they suggest all manner of dread things—disease, accidents, coming evil and unhappy lives. Sometimes, when such an odor comes between me and a beloved object, a nervous tremor seizes me, and I find it difficult to control myself.

In my reading I have found that the Russians and the French are very sensitive to the odors which bring me delight and pain. Shakespeare, too, is full of references to the olfactory sense. A number of passages occur to me which I will note: In the scene where Hamlet stands by the grave of Ophelia, and holds out the jester's skull to Horatio, he asks in effect, "Did not Alexander, think you, look like this on earth?" Horatio replies, "Even so," and Hamlet asks, "and smelt so?"

In "Macbeth," after the murder of Duncan, Lady Macbeth, gazing on her soft white hands, cries, "Out, damned spot! Out, I say. . . . Here's the smell of blood still; all the perfumes of Arabia will not sweeten this little hand." The smell-sensation, you see, is emphasized more than the sight of the blood-stain.

Juliet tells us

"that which we call a rose
Would by any other name smell as sweet."

Obviously, she is more impressed by the sweet smell of the rose than by its rich color or its exquisite petals.

When Juliet wonders what will become of her if she wakes in the tomb before Romeo comes, the odor-sense is skilfully employed to darken the picture:

"Shall I not, then, be stifled in the vault,
To whose foul mouth no healthsome air breathes in?
. . . .
Is it not like that I . . . with loathsome smells
. . . shall be distraught?"

(I am quoting from memory.)

In "Twelfth Night" the Duke says of music

"That strain again; it had a dying fall;
Oh, it came o'er my ear like the sweet south
That breathes upon a bank of violets
Stealing and giving odor."

In these most poetic lines we have hearing and smell linked together aesthetically. The rich notes of the violin are associated in my mind with the emission of fragrance from dew-bathed southern roses in early June. I suppose the first poet called the scent of a flower its breath; but perhaps he did not realize as Bacon did that a breath is a sound. In his essay, "Of gardens," he says, "The breath of flowers is far sweeter in the air . . . where it comes and goes like the warbling of music . . . than in the hand."

In "Cymbeline" Iachimo describes the sleeping Imogen, and declares:

"'Tis her breathing
Perfumes the chamber thus."

In the summer-time, when all the windows in my eerie study are wide open, the scents from the flowers and trees in the garden beat upon me in little, delicately panting waves, and somehow this sensation is associated in my mind with the song of birds and the open sky.

I do not know of any passage in literature which so exquisitely interweaves all the senses as Shakespeare's sonnet XCIX. I will quote it because it illustrates how I interpret the sensations which come to others through the eye and the ear with smell.

> "The forward violet thus did I chide,
> 'Sweet thief, whence didst thou steal thy sweet smells.
> If not from my love's breath? The purple pride
> Which on my soft cheek for complexion dwells,
> In my love's veins thou hast too grossly dyed.
> The lily I condemned for thy hand,
> And buds of marjoram had stolen thy hair;
> The roses fearfully on thorns did stand,
> One blushing shame, another white despair,
> A third, nor red nor white, had stolen of both,
> And to his robbery had annex'd thy breath;
> But for this theft, in pride of all his growth,
> A vengeful canker eat him up to death.
> More flowers I noted, yet I none could see,
> But sweet or color it had stolen from thee.' "

You see why I stress the importance of the sense of smell. I associate it with poignant memories, deep emotions and the glories of poetry.

I recall a description I once read in French—unfortunately, I cannot remember the author's name—of a man who stood on the seashore with the wind blowing in his face, full of heart-stirring odors. He threw up his arms ecstatically, taking in great "mouthfuls of air," as the French idiom so vividly expresses it, while his heart overflowed with tender memories. The scents from land and ocean brought back to him the loved hearth of his boyhood where he had gazed into the fire, seeing magical pictures, the kisses of his mother, the fine, virile personality of his father, the orchard where he had played, and the summer nights when he wandered under the stars with great thoughts in his brain. Throughout the passage it is the sensation of smell, not sight or hearing, which awakens the deepest emotions.

I wonder how many people are aware of the complex odors in a house that has been lived in for a long time. They give me a comfortable sense of hospitality. They suggest cheery winter fires and peace and sweet family intimacies. There are lingering scents of perfume and garments in closets and drawers, and appetizing odors of cookery, which some people find extremely unpleasant, but which seem to me kindly.

Balzac attached much meaning to the smells that came to him while he worked in his attic. He was sensitive to the odor of brown gravy and the exhalations from the city streets. He read much of charm, and of ugliness, too, into the smell of garments and the cosmetics people used.

Pierre Loti noticed the odor of the crisp winter air in his mother's cloak when she came into the room where he lay ill, and bent over him, rosy-cheeked and drenched in sunshine.

I was much interested in an article by Stuart Mackenzie in "The American Magazine" entitled "Smells are Surer than Sounds and Sights." He notes among other things that plants emit many odors beside the perfume of their blossoms. Sometimes the scents are in the wood itself, as in cedar and sandalwood, sometimes in the bark, as in cinnamon and cassia, or in the leaves, as in pines, bay, mint, thyme and lemon verbena. Others are in the fruits—orange, lemon and nutmeg. He has observed smells also in the seeds—almond and caraway, and I would add magnolia-seeds, and sometimes certain secretions are fragrant, like turpentine, and even roots have a strong odor, like the orris root. All this knowledge is a part of my equipment for getting joy out of life.

Mr. Mackenzie also says that he felt keenly his inferiority in the olfactory sense when he lived among some Western Indians. They could detect a distant camp-fire when he could not possibly perceive it. This makes me feel my kinship to the Indians; for I, also, can smell at a great distance.

Some day, when I have leisure, I will write you more on this fascinating subject. The Bible is crammed full of odor references. The patriarchal services had in them much of incense and sweet oil. If the elders who stand around the Throne of God hold in one hand golden harps, they hold in the other "Golden vials full of odours which are the prayers of the saints."

Sincerely and interestedly yours,

HELEN KELLER.

When tested objectively, Miss Keller's olfactory sense shows nothing above the normal average. Six aromatic substances were used in these tests, including alcohol, oil of wintergreen, peppermint, formaldehyde, eucalyptus and asafetida, with the results recorded in table 1.

TABLE 1.—*Estimation of Olfactory Sense* *

	Did Not Recognize	Recognized
Alcohol	1 to 32	1 to 16
Wintergreen	1 to 256	1 to 128
Formaldehyde	1 to 32	1 to 16
Peppermint	1 to 2048	1 to 1024
Eucalyptus	1 to 128	1 to 64
Asafetida	1 to 4096	1 to 2048

* Miss Keller's responses to olfactory tests correspond closely to the normal average.

In consequence of these tests, it may be said that the fundamental pathway for the sense of smell in Miss Keller does not have a demonstrable advantage in its peripheral organization.

The Sense of Taste.—Gustatory sense, a specialized portion of the seventh and ninth cranial nerves, also did not show any advantage in its fundamental organization.

The Sense of Sight.—Concerning vision, it may be said that Miss Keller is totally blind and has been in that condition since her nineteenth month. She can perceive neither light nor objects. Both retinae are absent. She therefore is deprived of the primary conduction paths for visual sense.

The Sense of Hearing.—With reference to the auditory sense, Miss Keller is completely deaf, having neither bone nor air conduction in either ear. Concerning her bone conduction, some question might arise as she is conscious of vibratory impressions. This, however, is in all probability due not to her auditory sense, but rather to an extraordinary development of her vibratory sensibility.

The Sense of Touch.—The analysis of Miss Keller's capacities in the sense of touch has been most carefully studied, and many measurements have been made by repeated testing. In these examinations, much care was exercised to prevent that fatigue which so commonly makes its appearance after the subject has been under observation for some time. When there was any doubt as to the figures obtained by these sensory measurements, they were repeated on another day. In fact, all of the estimations have been checked by frequent retesting. Sometimes the retest was made by the original observer, but just as often by a collaborator. Ultimately, an average figure was obtained from these several controls of each test.

Light Touch: The test for light touch was made by means of graded bristles corresponding with the von Frey instruments of this kind.

TABLE 2.—*Estimation of Light Point Touch* *

	Right Side of Face †				Left Side of Face			
Helen Keller	0.4/10	0.3/10	0.03/10	0.01/5	0.4/10	0.3/10	0.03/10	0.01/5
Average	0.4/10	0.3/10	0.03/10	0.01/5	0.4/10	0.3/10	0.03/10	0.01/5
	Right Forearm ‡—Ventral				Left Forearm—Ventral			
Helen Keller	0.4/10	0.3/10	0.03/10	0.01/5	0.4/10	0.3/10	0.03/10	0.01/5
Average	0.4/10	0.3/10	0.03/10	0.01/5	0.4/10	0.3/10	0.03/10	0.01/5
	Right Finger Tips—Palmar				Left Finger Tips—Palmar			
Helen Keller	0.4/10	0.3/10	0.03/2	0.01/0	0.4/10	0.3/10	0.03/4	0.01/0
Average	0.4/10	0.3/10	0.03/6	0.01/2	0.4/10	0.3/10	0.03/6	0.01/0
	Right Fingers—Dorsal				Left Fingers—Dorsal			
Helen Keller	0.4/10	0.3/10	0.03/10	0.01/4	0.4/10	0.3/10	0.03/10	0.01/5
Average	0.4/10	0.3/10	0.03/10	0.01/5	0.4/10	0.3/10	0.03/10	0.01/5

* Bristles in fractions of gram of tensile resistance. The denominator indicates correct responses in ten tests. The numerator indicates the bristle employed.

† "Side of face" includes four areas: forehead, supra-orbital region, cheek and chin.

‡ "Forearm" includes two areas: (a) elbow and (b) middle of forearm.

In so far as possible, the methods of cutaneous sensory testing employed by previous observers have been applied to Miss Keller. This refers not only to the type of instrument used but to the rules regulating the tests. In examining the state of cutaneous sensibility dependent on light touch, or what might be called "point touch," as the stimulus is limited to single points on the skin, a group of four bristles was employed. These bristles were numbered 1, 2, 3, 4, respectively. No. 1 had a tensile resistance of 0.4 Gm.; no. 2, a tensile resistance of 0.3 Gm.; no. 3, of 0.03 Gm., and no. 4, of 0.01 Gm.

Each bristle was applied to each point tested ten times successively, and the number of correct answers was noted for each bristle. In these tests, Miss Keller showed that she corresponded to the normal average in an exact and striking manner. The summary of these comparative tests is given in table 2.

Two-Point Recognition: The recognition of two points placed simultaneously on the skin is probably not merely confined to the operation of cutaneous receptors, but undoubtedly is influenced by the deeper receiving organs essential to the recognition of pressure. Two-point recognition, moreover, belongs unquestionably to a type of sensory organization requiring a higher level of cortical activity than that necessary for light touch. Indeed, it is a question in my mind whether two-point differentiation on the skin should not be considered as a higher sensory synthesis, particularly since it shows considerable variation in persons subjected to different degrees of training. This view may suffice to explain the discrepancies in observation made on different subjects. The instrument used for these tests was a pair of exactly calibrated calipers, the sharp points of which were slightly ground down to avoid producing pinpoint stimulation. Similar calipers with pointed ends were also employed as a control, but the figures obtained from them have not been tabulated since it appeared that the pressure elements of sensation entered too much into such tests. Dr. Byron Stookey's two-point esthesiometer was also employed in checking the observations made by other instruments. For practical purposes, it is the most convenient instrument for studies in two-point recognition.

In comparing Miss Keller's two-point tests with those of the normal person as averaged from ten normal subjects tested, there appeared to be no essential difference. Miss Keller's two-point recognition was the same as the normal average. This fact seems to be particularly interesting, since Dr. G. Stanley Hall, in consequence of similar tests of Laura Bridgman, found that she possessed a two-point recognition two or three times greater than that of the average person. My own experience with Miss Keller leads to some question as to the validity of Dr. Hall's conclusion, for in comparing figures which I have obtained with Helen Keller, I find that they correspond with remarkable closeness to those recorded for Laura Bridgman. As has been stated, Miss Keller herself is quite similar to the average normal adult; in fact, one blind girl whom I tested had a much greater acuity in two-point recognition than Miss Keller. Dr. Hall noted that Miss Bridgman could detect a distance of 0.5 mm. on the tip of her tongue; Miss Keller could do this also, and indeed it is possible for many normal adults.

In the tests of two-point recognition Miss Keller was able to detect the eye of a needle by applying the latter to the tip of her tongue and, having done so, she finally succeeded in introducing a thread into the eye after a period of concentration and—as she expresses it—patience. This same concentration and patience are, I believe, the secret of much of Miss Keller's sensory superiority.

As bearing on the differences between Laura Bridgman and Helen Keller in two-point recognition, there is a fact which seems to support the postulate already made, namely, that this form of sensation belongs to the higher orders of sensory syntheses, and is largely conditioned by training. For many years Miss Bridgman employed most of her spare time in doing needlework for pin money. She made much beautiful embroidery and developed great facility with her needle. This continued use of so fine an instrument as the needle would have served to train her two-point recognition to an extraordinary degree. It might be presumed that reading braille would similarly train two-point recognition, but the braille points are relatively coarse and the intervals between them are not small, so that such an exercise would not necessarily develop a high degree of sensory synthesis in two-point recognition, although Miss Keller is an untiring reader. She uses the typewriter a great deal, but she has not cultivated her needlework to the extent that Laura Bridgman did. It is on the grounds of this special training to which Miss Bridgman subjected herself that I attribute the difference in her two-point recognition which Dr. Hall claims was two or three times better than the normal average, and it is to the lack of such intensive training that I would attribute Miss Keller's less highly developed two-point recognition. I should feel that a two-point recognition two or three times greater than the normal, as Miss Bridgman's was said to be, is perhaps only approximate and may give a somewhat exaggerated idea of her actual capacities in this form of sensory perception.

TABLE 3.—*Estimation of Two-Point Touch Recognition* *

	Right			Left		
	Forehead	Cheek	Chin	Forehead	Cheek	Chin
Helen Keller	1.25	1.25	1.0	1.25	1.25	1.0
Average	1.50	1.50	1.0	1.50	1.50	1.0
	Arm	Forearm	Palm	Arm	Forearm	Palm
Helen Keller	7.50	5.00	3.0	7.50	5.00	3.0
Average	8.00	5.00	3.0	8.00	5.00	3.0
	Thumb	Finger	Thigh	Thumb	Finger	Thigh
Helen Keller	1.00	1.00	25.0	1.00	1.25	25.0
Average	1.25	1.25	25.0	1.25	1.25	25.0
	Calf	Foot	Toes	Calf	Foot	Toes
Helen Keller	20.00	5.00	1.5	20.00	5.00	1.5
Average	22.00	5.00	1.5	22.00	5.00	1.5

* The separation distance is expressed in millimeters.

It is my conclusion that Helen Keller does not show any advantage in two-point recognition over the normal average, and such advantage as Laura Bridgman is said to have manifested should be ascribed to special training in the associations of this complex sensory synthesis.

A comparative summary of Miss Keller's two-point touch recognition is given in table 3.

Touch Localization: In the tests of touch localization, it was necessary to employ a somewhat specialized method in order to obtain clear responses from Miss Keller. To do so, I asked her to indicate on the surface of the skin the point where I touched her. The observer employed a fine pencil point of soft lead. Miss Keller herself also used a similar lead pencil. The point touched by the observer left a small black dot on the skin. In endeavoring to locate this point Miss Keller's pencil also left a dot on the skin. The distance between these two points was measured to show the error in exact localization. The same method was employed in testing the normal adult controls. There is always considerable error in this touch localization, varying in the normal person from 3 to 25 mm. or more, depending on the area. Miss Keller's margin of error was no greater and no less than that of the average.

Table 4.—*Estimation of Touch Localization*

	Right			Left		
	Forehead	Face	Chin	Forehead	Face	Chin
Helen Keller..........	4.0	3.0	3.0	4.0	3.0	3.0
Average..............	3.5	3.0	2.5	3.5	3.0	2.5
	Shoulder	Arm	Forearm	Shoulder	Arm	Forearm
Helen Keller..........	25.0	22.0	20.0	25.0	22.0	20.0
Average..............	22.0	20.0	20.0	22.0	20.0	20.0
	Palm	Thumb	Fingers	Palm	Thumb	Fingers
Helen Keller..........	4.0	4.0	4.0	4.0	4.0	4.0
Average..............	4.0	4.0	4.0	4.0	4.0	4.0
	Knee	Calf	Foot	Knee	Calf	Foot
Helen Keller..........	25.0	25.0	15.0	25.0	25.0	15.0
Average..............	25.0	25.0	15.0	25.0	25.0	15.0

In evaluating touch localization, it must be regarded as a fairly high degree of tactile discrimination. It certainly involves more than the cutaneous receptors, especially as the test was devised and applied in this study. The pressure sense entered into the sensory syntheses necessary to the sensation. Such stimuli are essential to touch localization if it becomes accurate, although light touch may be fairly well localized, as, for example, the crawling of an insect over the skin. But I have noticed in myself that localization unaided by vision has a somewhat wider margin of error than when a certain degree of pressure enters the synthesis. My conclusion, therefore, is that the most accurate touch localization depends on subcutaneous receptors cooperating with those in the skin itself.

The summary of Miss Keller's touch localization in several parts of her body is given in table 4.

Testing Cutaneous Sense by Electric Currents: One of the most useful and accurate means of testing skin sensation is by the use of a small examining electrode (1 cm. in diameter) by the aid of which a faradic current is applied to different parts of the body. I have standardized this means of testing through many examinations, using an inductorium of 1,000 coils over the primary, and estimating the point of sensory perception in centimeters of coil distance over this primary. The results of tests of Miss Keller over different areas are in close accord with those of the normal average person. The summary of these tests is given in table 5.

The galvanic current was also employed in estimating the acuity of skin sensation. The records were here made in milliamperes from the cathode applied as the examining electrode. In these tests, Miss Keller corresponded closely with the normal average.

Table 5.—*Estimation of Faradic Touch—Induction, 1,000 Coils* *

	Right Ventral Surface			Left Ventral Surface		
	Neck	Arm	Wrist	Neck	Arm	Wrist
Helen Keller..........	2.2	4.0	3.9	2.2	4.2	3.9
Average..............	2.5	4.0	3.5	2.5	4.0	3.5
	Right Dorsal Surface			**Left Dorsal Surface**		
	Neck	Arm	Wrist	Neck	Arm	Wrist
Helen Keller..........	2.2	3.6	3.0	2.2	2.6	3.0
Average..............	2.5	3.0	3.0	2.5	3.0	3.0

	Right Finger Tips—Palmar					Left Finger Tips—Palmar				
Helen Keller..........	3.3	3.0	3.0	2.6	2.4	3.0	3.0	2.7	2.7	2.1
Average..............	3.0	3.0	2.5	2.5	2.5	3.0	3.0	2.5	2.5	2.5
	Right Fingers—Dorsum					**Left Fingers—Dorsum**				
Helen Keller..........	3.8	3.5	4.0	3.2	4.0	3.6	3.4	3.5	3.2	3.5
Average..............	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

* Estimated in centimeters of coil distance.

Pressure Sense: Tests were made by means of a pesometer in which the differentiation in focal pressure on the points of the skin was estimated in grams. The diameter of the surface applied to the skin in the pesometer used was 1 mm. As a result of these tests, Miss Keller was found to correspond accurately to the normal average adult. A summary of focal pressure differentiation in grams is given in table 6.

Surface pressure was measured as compression by means of a cuff in connection with a manometer, the pressure being recorded in millimeters of mercury. These compression tests gave the following results:

In increase in pressure of from 10 up to 40 mm. a rise of 1 mm. and a fall of 2 mm. were detected on both arms, forearms and hands. A rise of 1 mm. and a fall of 2.5 mm. were detected on both thighs. A rise of 2 mm. and a fall of 1 mm. were detected in both legs at about the middle of the calf. In compression tests in which the mercury column rose from 40 to 140 mm., the interval of differentiation was somewhat wider. On both arms, forearms and hands a rise of 5 mm. and a fall of 10 mm. were detected. In both thighs and legs a rise of 5 mm. and a fall of 10 mm. were appreciated. These tests as applied to Miss Keller gave results with which the control tests in ten normal adults corresponded with such minor variations that the differences were negligible. In other words, the measurements of Miss Keller's pressure sense by compression were similar to those of the normal average.

Temperature Sense: The temperature component of contact sense has always created great difficulties in metrical estimation. The procedure followed in evaluating this type of sensibility in Miss Keller was a series of tests by means of electric thermophores. Two thermophores were used, each set at a different temperature. Each was maintained constant by means of an adjustable rheostat. The surface applicator was circular and measured 5 mm. in diameter. One thermophore was set at 98.5 F. and the other at 100 F. The applicator was allowed to remain on the skin for four seconds; an interval of four seconds elapsed before the second application was made, during which the applicator was held in position for four seconds also. It was found that neither Miss Keller nor any of the normal adult controls was able to distinguish less than 1.5 degrees F. in the most sensitive parts of the body. The two thermophores applied in the manner indicated to the forehead, cheek and chin of both sides, to five areas on the arm and forearm, to six areas of the palmar and dorsal surfaces of the hand, to each phalanx of all of the fingers on both sides and to two areas on the chest and on the abdomen, gave prompt and accurate responses. Two areas on the thigh, the calf and the dorsum of the foot gave accurate but somewhat hesitating responses on both sides. With the thermophores set at 120 and 110 F.,

Table 6.—*Summary of Focal Pressure Differentiation (in Grams)*

	Right			Left		
	Upper Part of Face	Lower Part of Face	Shoulder	Upper Part of Face	Lower Part of Face	Shoulder
Helen Keller..........	3.2	3.5	9.4	3.2	3.2	9.4
Average..............	3.5	3.5	9.0	3.5	3.5	9.0
	Arm	Forearm	Palm	Arm	Forearm	Palm
Helen Keller..........	9.0	8.4	6.4	9.0	8.2	6.4
Average..............	9.4	8.0	6.0	9.4	8.0	6.0
	Back of Arm	Back of Forearm	Back of Head	Back of Arm	Back of Forearm	Back of Head
Helen Keller..........	9.4	9.4	7.25	9.4	9.4	9.4
Average..............	9.4	9.4	9.4	9.0	9.4	9.4
	Forefinger	Middle Finger	Ring Finger	Forefinger	Middle Finger	Ring Finger
Helen Keller..........	5.2	5.2	5.2	5.2	5.2	5.2
Average..............	5.2	5.2	5.2	5.2	5.2	5.2

respectively, following the same method of testing over the same areas indicated in the previous tests, the responses obtained were all prompt and accurate except on the back of both thighs where there was considerable hesitation, but a response which eventually was accurate. In all of these tests, Miss Keller corresponded closely with the normal average adult controls (table 7).

Vibratory Sense: The vibratory component of sensibility was also measured. In this connection, it should be noted that this sense is by no means dependent alone on bone for its ultimate conduction. Vibration is easily felt on the skin, as when applied on the web between the thumb and the index finger or other fingers. Vibration may be perceived on regions of loose skin picked up between the thumb and finger, without the intervention of the bony system. Vibration sense plays an extremely important rôle in the information that it conveys to Miss Keller. She is able to distinguish much that is going on in the household through this sensory avenue. When she is in her study writing, meal time is announced to her by some one stamping on the floor in the dining room. She is able to recognize this stimulus on the floor above. To a certain extent she can distinguish different persons by their tread on the stairs or on the floor. Seated in her own room, she is able to recognize the flight of airplanes passing in the vicinity of her home. This, of course, is an example of vibration transmitted to the body through the air from a distant source of stimulation. It illustrates some of the inconsistency in regarding vibratory sense as restricted to actual contact sensibility. Miss Keller is also able to recognize the difference between the vibrations produced by implements used in the house, such as sawing, planing or hammering; but her most remarkable development in vibratory perception is her latest achievement of "listening" to the radio by means of

TABLE 7.—*Temperature Discrimination Estimated by Thermophores* *

	Right			Left		
	Cheek	Neck	Shoulder	Cheek	Neck	Shoulder
Helen Keller..........	1.5	1.5	1.5	1.5	1.5	1.5
Average..............	1.5	1.7	1.5	1.5	1.7	1.5
	Arm	Forearm	Palm	Arm	Forearm	Palm
Helen Keller..........	1.5	1.5	1.5	1.5	1.5	1.5
Average..............	1.5	1.5	1.5	1.5	1.5	1.5
	Fingers	Chest	Abdomen	Fingers	Chest	Abdomen
Helen Keller..........	1.5	1.5	1.5	1.5	1.5	1.5
Average..............	1.5	1.5	1.4	1.5	1.5	1.4
	Thigh	Leg	Foot	Thigh	Leg	Foot
Helen Keller..........	1.5	1.5	1.5	1.5	1.5	1.5
Average..............	1.4	2.0	2.0	1.4	2.0	2.0

The estimations made were in degrees Fahrenheit between 98.5 and 100.

her hands. A special loud speaker has been constructed for her under the direction of Mr. Keith Henney. Miss Keller finds much enjoyment in the radio programs which she hears in this way. Up to the present time she has not learned to interpret spoken language on the radio, but she has a keen appreciation of music and is able to distinguish different selections which she has previously heard. She gives evidence of her musical appreciation by her change of expression. Slow and sad music causes a serious expression. Quick music and dance music cause her to manifest rhythmic actions characteristic of dancing. Another remarkable achievement in utilizing the vibratory sense is seen in her ability to interpret spoken language by placing her hand on the face of the speaker so that the thumb rests on the larynx, the middle finger on the lips and the index finger on the ala of the nose. Thus she distinguishes the vibratory effects of articulation and can follow conversation with ease. An interesting picture showing Miss Keller thus engaged appears in one of her books, "The Story of My Life." Here she is shown conversing with Mr. Joseph Jefferson and her teacher, Mrs. Macy. They are apparently holding an animated conversation in which Helen Keller is not the least enthusiastic participant.

In testing Miss Keller's vibratory sense, two metrical procedures were employed: The first was the application of tuning forks with 128, 256, 512, 1,024 and 2,048 vibrations, respectively. The highest vibration that Miss Keller was able to perceive by this means in any part of her body was 1,024 (high *C*), but for most areas of her body her highest range was 512 (C_2). The second procedure employed was the Henney pallesthesiometer, which records on a scale of radio cycles. This is a new instrument, especially devised for measuring Miss Keller's vibratory perception and for which I am indebted to Mr. Keith Henney. It is extremely delicate and gives with great accuracy the upper and lower ranges of vibratory sensation received from all parts of the body.

A third method was employed for testing surface vibration, in which vibratory sensation over large areas of the body was examined by an especially devised loud speaker mechanism attached to the pallesthesiometer. In all of these tests, Miss Keller's range of vibratory sense corresponds strikingly to that of the normal average.

A summary of vibratory sense as tested by tuning forks and the pallesthesiometer is given in tables 8 and 9.

Motion Sense: In the next observations, tests were made of postural and motion sense. The first of these was the actual measuring of motion sense for which a new instrument was designed, called the "kinemometer." This instrument is so arranged that it is capable of measuring changes in the limbs or parts of the limbs in millimeters. It consists of a platform on which the part to be studied may be placed.

The platform itself may be elevated or depressed by means of a delicately adjusted worm-screw and the distance of such motion measured in millimeters. The movable platform is so divided that the entire limb, the hand, or each finger, as well as the several joints of the finger, may be moved separately and the range of motion perception thus recorded.

TABLE 8.—*Estimation of Vibration Sense by Tuning Forks* *

	Right			Left		
	Upper Part of Face	Middle Part of Face	Lower Port of Face	Upper Part of Face	Middle Part of Face	Lower Port of Face
Helen Keller..........	1,024	1,024	1,024	1,024	1,024	1,024
Average..............	1,024	1,024	1,024	1,024	1,024	1,024
	Occiput	Acromion	Olecranon	Occiput	Acromion	Olecranon
Helen Keller..........	1,024	1,024	1,024	1,024	1,024	1,024
Average..............	1,024	1,024	1,024	1,024	1,024	1,024
	Carpus	Fingers	Spine	Carpus	Fingers	Spine
Helen Keller..........	1,024	1,024	512	1,024	1,024	512
Average..............	1,024	1,024	512	1,024	1,024	512
	Knee	Shin	Ankle	Knee	Shin	Ankle
Helen Keller..........	512	512	512	512	512	512
Average..............	512	512	512	512	512	512

* Oscillations indicate 1,024 (C^3), 512 (C^2).

TABLE 9.—*Focal Vibration Sense Measured by Pallesthesiometer in Radio Cycles*

	Right			Left		
	Mastoid	Neck	Shoulder	Mastoid	Neck	Shoulder
Helen Keller..........	1,100	1,100	1,100	1,100	1,100	1,100
Average..............	1,100	1,100	1,100	1,100	1,100	1,100
	Occiput	Scapula	Elbow	Occiput	Scapula	Elbow
Helen Keller..........	1,600	1,100	900	1,600	1,100	900
Average..............	1,600	1,100	1,000	1,600	1,100	1,000
	Forearm	Wrist	Palm	Forearm	Wrist	Palm
Helen Keller..........	1,300	1,000	1,600	1,300	1,000	1,700
Average..............	1,300	1,100	1,600	1,300	1,100	1,600
	Thumb	Fingers	Shin	Thumb	Fingers	Shin
Helen Keller..........	1,400	1,400	520	1,400	1,400	520
Average..............	1,400	1,400	520	1,400	1,400	520

The summary of motion sense measured in millimeters is given in table 10. From these tests, it is evident that Miss Keller is, if anything, less acute in the recognition of motion than the average normal adult.

Posture Sense: Posture sense was measured by means of the kinemometer, and it was found that postures of the hand, fingers and arms were accurately appreciated by Miss Keller, although she did not show a greater capacity in this respect than the normal average.

Balance Sense: The estimation of balance sense was made by means of a rotation chair, by the Romberg position, by rotation in the standing position and by the Hitzig galvanic stimulation of the vestibule. Miss Keller showed on rotation that she did not possess a sense of direction. The rotation did not cause visceral sensation of any variety. The test of rotation for nystagmus was omitted, as certain ocular operations precluded such reactions. It is interesting in this connection to note again that Miss Keller does not possess retinas, and this, in conjunction with the fact that she is devoid of any sense of direction, may have an important bearing on certain but little understood sensory pathways connected with the eye. After repeated tests in the rotation chair, Miss Keller was able to designate with a certain degree of accuracy the direction in which she was being moved. She believed that her perception in this regard might be explained by air currents striking her face as the chair rotated in one direction or the other. Her spatial orientation in limb movement and general coordination was perfect. This was determined by tests for nonequilibratory as well as equilibratory coordination. Miss Keller was found to possess a perfect sense of balance, in spite of the fact that there was no response from the semicircular canals of either side to cathodal or anodal stimulation of the Hitzig tests. I refrained from making the caloric tests during this series of observations, but for completeness I hope to add them in a subsequent report.

TABLE 10.—*Estimation of Motion Sense* *

	Right Joint Flexion			Left Joint Flexion		
	Elbow	Wrist	Thumb	Elbow	Wrist	Thumb
Helen Keller..........	3	3	3	3	3	3
Average..............	2+	2+	2+	2+	2+	2+
	Right Joint Extension			**Left Joint Extension**		
	Elbow	Wrist	Thumb	Elbow	Wrist	Thumb
Helen Keller..........	2	2	2	2	2	2
Average..............	1+	1+	1+	1+	1+	1+
	Right Joint Flexion			**Left Joint Flexion**		
	First Phalanx	Second Phalanx	Third Phalanx	First Phalanx	Second Phalanx	Third Phalanx
Helen Keller..........	3	3	3	3	3	3
Average..............	2+	2+	2+	2+	2+	2+
	Right Joint Extension			**Left Joint Extension**		
	First Phalanx	Second Phalanx	Third Phalanx	First Phalanx	Second Phalanx	Third Phalanx
Helen Keller..........	2	2	2	2	2	2
Average..............	1+	1+	1+	1+	1+	1+

* This sense was measured in millimeters by the kinemometer.

The Hurt Sense: Analysis of the hurt sense showed that to the pin point measured by the algesimeter in millimeters, to steady pressure, to sudden compression, to extremes of temperature, to vibrations below 100 oscillations, to overextension or overflexion of joints, Miss Keller's discomfort was essentially the same as that in the normal controls. The algesimeter applied to the fingers (all of the phalanges) and to the same area of both palms, to the back of the hand, to the forearm and arm, to the entire face on both sides and to the leg and foot gave the same rating for Miss Keller as for normal adults.

Overextension of the wrist and the several joints of each finger of both hands caused discomfort at the same degree of extension as in the normal. Temperature at 110 F. was uncomfortable and at 120, disagreeable and tending to be painful. Steady thrusts at a pressure of 10 pounds on the back of either hand became disagreeable and if continued for several seconds, almost painful. Compression on both arms and forearms, as well as on both legs, at 130 mm. of mercury became uncomfortable, and at 150 mm. became disagreeable and painful. It is possible that if Miss Keller's hurt sense is actually less acute than in the normal person, this difference may be explained by the fact that there is a degree of stoicism in her philosophy which permits her to endure pain and distress with more fortitude than most normal persons possess.

SENSORY SYNTHESES

It seems likely that the several components of contact sense are seldom employed singly. Most of one's contacts with the world depend on various combinations of these several contact components. For example, the recognition of different states of matter such as fluidity, viscosity or solidity depends on stimuli of surface touch, spreading touch, surface and spreading pressure and surface temperature, as well as motion in the several parts making the contact. Not only must these elements enter into a sensory composite which gives the actual picture of the situation examined, but almost photographic memory of these conditions must be made and retained in the brain. Correlation with other types of sensation is also essential in order to permit of proper object association, recognition and naming. The texture, the size and the shape of objects with which one comes in contact through the sense of touch likewise require composite associations of the several sensory elements. One of the most important of these composites is the recognition of objects by palpation, the sensory process of which is called stereognosis. In this capacity, Miss Keller showed an extraordinary richness of association dependent on many sensory qualities derived from surface touch, surface pressure, surface vibration and surface temperature in combination with sensory elements of motion and posture. Miss Keller's stereognosis is much above that of any normal person whom I have ever tested. Not only is she able to recognize all familiar objects about her, to tell the form and size of many articles with which she has not had previous contact, but she also has the ability to identify by touch the difference between a great variety of flowers and plants. This is a feat far above the capacity of most average persons even when aided by all of the senses. After testing her capacity for the recognition of form with many different objects, I placed in her hand a coin, telling her that this was the one touch of nature which made all men kin. Her immediate answer was—"Pessimist." Such a response showed not merely a great rapidity in the assemblage of sensory associations related to touch but an equally quick wit and broad understanding of the world.

Miss Keller's sensory organization for the primary conduction of afferent impulses thus does not appear to be different from that of the average run of humanity. Her sensory supremacy is entirely in the realm of intellect. Here she has developed a richness of association far surpassing that of the average adult. She seems to be exceptionally capable even for the class rated as intellectual.

SENSORY DEVELOPMENT OF LAURA BRIDGMAN

A comparison of Miss Keller's sensory equipment with that of Miss Laura Bridgman is important since all of the conclusions drawn from Miss Keller gain substantiation from this comparative study. During her life, Laura Bridgman was the subject of careful examination by Dr. G. Stanley Hall, who recorded the results of his investigations in 1879.

She was born in Hanover, N. H., in 1829, and died in 1889. Her family were farming people of sound health, good habits and average height. Both parents were rather nervous. Miss Bridgman's mother had an active mind. Laura is said to have inherited the physical peculiarities of her mother. She had convulsions during infancy and was quite delicate. When 24 months of age, she had a severe attack of scarlet fever. Both of her eyes and her ears suppurated. She was kept in a darkened room after this sickness, and was so feeble for two years that she could not sit up unsupported. The illness left her deaf and blind and, to a great extent, deprived of smell and taste. The sight in the left eye was entirely lost. With the right eye she perceived some sensation from large and bright objects up to her eighth year, but after that time she was completely blind. When she was 5 years of age, her strength began to return, and toward the end of her eighth year she was sent to Dr. Howe, of the Perkins Institute, in order that she might be educated. As a result of her long illness, all recollections of babyhood had been effaced. Before her education was seriously undertaken, she had received some training at home. She was able to do a little sewing, knitting and other household tasks. Her parents kept her as much as possible in the sunlight, so much indeed that she often complained of a slight pricking like that of needles in the left eye. She always wore a band of green silk over her eyes. In her early years at home she became familiar with the objects about her, as to their form, weight, density and temperature. Dr. Hall believed that only most elementary impressions from the sense of sight could have helped with her mental growth. She seems to have had some conventional notions of color in which she took great interest. It is believed that by her delicacy of touch she could distinguish green and white squares; yet on actual testing, she had no real idea of color. Dr. Hall believed that she was less blind-minded than many of the congenitally blind.

When she was 10 years of age, she wrote her name legibly for the first time. She then revisited her home, recognized her father at once by touch, tasted and recognized her mother's cooking, and taught her mother the finger alphabet. She had an astonishing accuracy in measuring time, as it seemed, by intuition. She did not possess a watch until much later. Her sense of touch at this age was acute, even for the blind. It was difficult to pass her in the hall without being recognized. Her judgment of distance was extremely accurate, and she continually practiced in feeling the objects about her. When she was 12 she developed the ability of knowing when any one touched the piano in the same room. She said the sound came through the floor to her foot and up to her head. Many of those about her thought that she was possessed of the sixth sense. It was never necessary for her to feel or grope her way about. In all her goings and comings she went straight like a bee, seeming to possess a remarkable sense of direction. She was so sensitive to vibrations that when the bell of the Perkins Institute was out of order she, who had never heard it, missed its vibrations more than anyone else.

During most of her adult life she was able to sew by hand and on the machine, and did much work of this kind. Her education, undertaken by Dr. Howe, led him to surround her with many restrictions, the psychologic justification of which may be questioned in the present day. He never permitted her to be fondled or caressed. He would not allow her to associate with boys or men and even in his own contacts with her he was most circumspect, avoiding anything but the most limited expressions of approval or disapproval. The theory which dictated this course of Dr. Howe's had its origin in the belief that all stimuli which might engender or arouse sexual feeling should be rigorously excluded. The result of these restrictions was a life very much shut in, one characterized by not a little prudishness and eccentricity. In this respect Laura's training differed greatly from that employed by Mrs. Macy with Helen Keller. Miss Keller's quick and happy responses, her brightness and charm in all social relations bespeak the development of a delightful inner life, a spirit untouched and unspoiled by coarse associations but abounding in sympathy, understanding and love.

From a psychologic point of view, these two remarkable women afford illustrations with striking contrasts as to the manner in which the human mind may be conditioned by the training. Mrs. Macy believes that Laura Bridgman possessed a remarkably brilliant mind with critical faculties perhaps even superior to those of Helen Keller. But, however brilliant this mind may have been, it had little of the richness of Miss Keller's. Laura's education came to an end when she was 20, due to the fact that her teacher, Dr. Howe, married at this time. The steps in her education as conducted at the Perkins Institute were formulated from those used in the case of Julia Brace. She was first taught the name of common articles by pasting the names in raised letters on these articles. The second step was the association of the word with the article; then she formed her words from separate letters, and finally learned the alphabet.

In all of her training it was necessary to hold her back, because she was most diligent and intent on her study. Through her entire life she made use of but fifty or sixty special vocal sounds. All of these were monosyllabic and seemed to have been spoken as if by accident. Nevertheless, it is believed that she might have been taught to vocalize. She was thought to be eccentric but not defective. She seemed to lack certain data of thought, but not in any marked way, while her power to use what data she had was exceptional. Concerning the condition of her mind, Dr. Hall, who studied her carefully, found no reason to believe that she remembered anything previous to her childhood illness.

Although it is impossible to express in measurable terms the result of Laura Bridgman's sensory tests as, for example, in the case of Helen Keller, the several sensory components were carefully studied by Dr. Hall, and his summaries in this regard furnish a basis for this comparison.

The Sense of Smell.—The olfactory sense was always defective. It contributed little to her development. In the early years of her life it is doubtful whether she had any true olfactory perception, and she never had a habit of holding articles to her nostrils. At 49 years of age, when she was tested, she did like to smell flowers, a few of which she could distinguish. Sometimes she was able to recognize cologne. She was also able to identify ammonia, but in this case it is questionable whether the identification was due to olfactory stimulation. The responses may have been dependent on the irritating effects of the ammonia. She sometimes recognized and distinguished tobacco and onions, but only when the odor from them was quite strong. Apparently there was no difference between the olfactory perception of the two nostrils.

It is at once apparent, in comparing the olfactory sense of Helen Keller and Laura Bridgman, that a great disparity exists between them. The sense of smell was much less developed in Laura Bridgman than in Helen Keller, who has distinguished it among her senses as her "landscape" or "background."

The Sense of Sight.—After her eighth year Laura Bridgman was totally blind, and such vision in her right eye as she did retain from her second year until this time was of little service to her. The contributions to the sensorium in both cases, therefore, were on a par, and vision as such did not contribute more to Laura Bridgman than it did to Helen Keller. It should not be overlooked that in one particular the two cases present a marked and perhaps far-reaching difference in the organization of vision. Laura Bridgman retained her eyes until the end of her life. Miss Keller has for many years been entirely deprived of her retinas. In this detail alone, the structural conditions in the sensory organizations of these two women differed. It may be that the wonderful sense of direction possessed by Miss Bridgman can be attributed to the fact that she retained her retinas, although they were devoid of visual function. Miss Keller's total lack of the sense of direction may in this sense be ascribed to the fact that she does not posses retinas. LeMoine compared the surprising sense of direction in Laura with that of migrating fish, and also of the bat. He thought that there must be a sixth sense, the reactions of which take place at the surface of the body.

The Sense of Taste.—The gustatory sense was much impaired. Miss Bridgman was less sensitive to bitter and acid, and most sensitive to salt and sweets.

The Sense of Hearing.—The tests for hearing indicate a complete loss of audition in both ears. Laura was tested by heavy tuning forks with the stems placed between her teeth. Heavy tuning forks were used with Helmholz resonators. Pasteboard trumpets were fitted to her ears, and electric stimulation was applied to various parts of the external ear, but to no avail. On one occasion she said she thought she heard something like singing or talking. Generally her only feeling was one of vibration or jar. Her perception and conception of vibration seemed so close to ordinary auditory consciousness that a close relationship is suggested between these two elements of sensation.

The Sense of Touch.—Compared with Weber's table, experiments on Laura Bridgman seemed to indicate that her tactile sense was two or three times as great as that in an ordinary person, but in these tests she showed great variations. Dr. Hall was of the opinion that the acuteness of the sense of touch was centrally conditioned, due to her unusual energy of concentration. Spots were found indicating partial dermal anesthesia. Sometimes she claimed to be sensitive to an imperceptible particle of dust, but repeated tests seemed to indicate that this was probably imaginary. In general, she had developed tactile sensation to such an extent that she could estimate the age of visitors by feeling the wrinkles about the eye; she could tell the frame of mind by touching the face; she could also detect the degree of intelligence by the tonicity of the muscles or movements of the hands. From a characteristically flabby hand, she almost immediately recognized idiocy. All of the last mentioned sensory abilities belong to the group of stereognostic elaboration. They indicate how closely in parallel with Helen Keller Laura Bridgman had developed this sensory capacity. Dr. Hall found that the two compass points showed Laura's discrimination to be two or three times better than that of the person who can see.

My interpretation of this difference between Laura Bridgman and Helen Keller has already been given, as well as my opinion as to the value of such a generalized comparison in the analysis of sensation.

Laura's facial sense was not well developed, yet her hands and face seemed to be the most sensitive parts of her body. It was supposed that she could recognize the approach of another person by the undulations of the air on her face.

The Temperature Sense.—Miss Bridgman was not remarkably sensitive to temperature.

The Vibratory Sense.—Miss Bridgman was extremely responsive to vibration. She often spoke of herself as hearing through her feet. In this particular she resembles Miss Keller, who "listens" to the radio with her hands and hears the sounds about the house through her feet. In this way she also distinguished step and voice. From rough preliminary experiments, it would seem as though Laura had been able to distinguish a musical interval of less than one octave by touch through her right index finger. She was conscious of vibrations in her throat when she made vocal noises. From these facts it was thought that the physiologic basis of her vibratory sense might have had some characteristics of a distinct sense. On the other hand, so far as may be judged from such tests as were applied to this element of sensation, Miss Bridgman did not seem different in any way from Miss Keller. It is, of course, unfortunate that metrical records do not exist in this respect, although there is nothing in the reports of Dr. Hall which warrants the belief that Laura Bridgman had any superiority in the organization of her primary pathways for vibratory sense.

The Motion and Position Sense.—The meager records of the motion and position sense leave some doubt as to the exact fundamental organization in Miss Bridgman's postural and motion sense. Judged by her general capabilities and her skilled acts, it would seem fair to presume that these components were normally developed.

The Balance Sense.—In this regard, Miss Bridgman was most sensitive. She did not have ataxia of any kind. She reacted quickly to rotation which made her dizzy and produced nausea. Her semicircular canals and their nerves were said to be in good condition. She was extremely sensitive to disturbance in equilibrium, and labyrinthine impressions appeared to be normally acute.

Sensitiveness to heat, to pressure and to electric stimulation were all below the average. As to her visceral sensation, according to Dr. Hall, she never developed heart or liver consciousness.

COMPARISON OF HELEN KELLER AND LAURA BRIDGMAN

If the lives of these two remarkable women could be considered in parallel columns, certain contrasts would be evident at a glance. There would be no doubt that Miss Keller has led a fuller life, one characterized by a greater variety of interests, more extensive contacts, greater depth of mental content and more impressive influence on her time. Laura Bridgman's limitations were largely those of circumstance. While she was not the first person of her kind to be subjected to training for the deaf and blind, much of her instruction depended on improvised innovations, and the experiments in her education were often too narrowly conceived. That she had a splendid mind seems clear. Her more or less secluded existence and limited mode of expression made it impossible for her to impress herself on a large circle of friends and acquaintances. She is known for the example she set rather than for the immediate influence which she had on her day. Quite the reverse is true of Miss Keller. She has lived a more normal life in constant intimate contact with her environment, exerting her influence on all those around her and radiating a cheery and wholesome spirit throughout the household of which she is the beloved center. She has made many friendships with important and interesting persons of her day. None of these is more touching in its remarkable understandings than that with Mark Twain. Mr. Clemens' regard for Helen Keller is expressed in many letters and in some of his writings. He appreciated her intellect, her lovable disposition, her rare social gifts. He was impressed above all by her marvelous achievements, especially that information and insight concerning the world around her by which she has learned to express herself so forcibly in spite of almost insuperable handicaps. Joseph Jefferson was another who delighted in a charming friendship with Miss Keller. In their numerous visits together, the great comedian would often play for her certain scenes of his famous comedies. She followed his acting merely by touching him, and appreciated his whimsical humor in a way that was perhaps denied to many of his more formal audiences.

Dr. Alexander Graham Bell also enjoyed the privileges of Miss Keller's intimate friendship. She numbers among her friends many authors, distinguished publishers, men of science and artists, with whom she carries on an interesting correspondence. But it is not through her capacity for friendship alone that she spreads her influence. She has done much thinking, and from her great fund of reading is able to draw most interesting and telling comparisons between the present times and the past. She has strong opinions which her special gifts and education enable her to express most effectually. Her views concerning policies and events, personalities and political topics are always interesting. It is not necessary to dwell here on her literary style or on her mastery of literature. An example of this has already been given in her letter to me concerning the significance of olfactory sense. She has decided religious convictions and a philosophy of life which have grown out of her long meditations. One feature concerning this philosophy is the almost complete displacement of physical fear, particularly the fear of death. Miss Keller is quite stoical in these respects. I have been surprised to see the equanimity with which she bore the suffering incident to a fall in which she seriously injured her knee. I have also noted previously the fact that painful stimuli seemed to cause her less distress than is felt by the normal average adult. Perhaps Miss Keller is different from other persons in her lack of fear concerning disease and death, because she firmly believes that with the passing of this life she will enter another in which all of those senses whose privileges she has here been denied will be restored to her in full, and she will then be able to hear, and to see, and to extol the glories of a new world thus revealed to her.

The differences between Miss Keller and Miss Bridgman seem to be in direct proportion to the methods of training, and to their teaching. The principles of education underlying the training of these two women were decisively different. Dr. Howe surrounded Laura Bridgman with restricted regulations and puritanic limitations. These resulted in her exclusion from many contacts with life which would have liberalized her attitude and amplified her reactions. Her religious beliefs consisted largely of the rigorous tenets derived from early pioneer days. Her understanding of life was conditioned by a thoroughgoing puritanism. Her teacher, Dr. Howe, was responsible for all of this, and doubtless himself believed that all of his pedagogic methods had a righteous as well as a wise foundation.

The fact that Laura's life was less full than Helen's must in large measure be attributed to the fact that her education ceased when she was 20 years of age, and that her discipline depended on fixed times and set exercises. The method of Mrs. Macy in developing Helen Keller was totally different. From the very beginning of her instruction this ingenious teacher has arranged every experience so that it might have real pedagogic value, whether in play, in work or in rest, as well as in all other social activities. Helen Keller has been taught to capitalize every opportunity for learning from each impression entering her sensorium. This began when she was 7 years old and continues to the present day. The mind which started to unfold in childhood under the wise guidance of an exceptional teacher has continued its progressive expansion with each succeeding year. There are those who believe that Mrs. Macy operates in some occult way on Helen Keller's mind and that many of her achievements are due to some mysterious influence or suggestion exercised by the teacher over the pupil. This, in the main, is pure fiction. The relation which exists between them is that of mother and daughter. But the daughter has decided notions of her own, which even filial devotion frequently will not restrain. Their religious outlook, for example, is totally different. Where they are at one, however, is their mutual belief and implicit confidence in the methods of training and education which have made Helen Keller's mind what it is.

In the ultimate adjustments to life of Laura Bridgman and of Helen Keller, there are also certain striking differences, differences, however, which seem to be directly attributable to educational opportunity. In this respect there can be no doubt that Helen Keller has been most highly—indeed, exceptionally—favored. Both women manifested a definite degree of dependence. They needed the assistance of others to make amends for the lack of sight and hearing. For example, they could not go about freely and safely in the midst of the congested conditions of ordinary life. Many of their contacts required an intermediary for their proper interpretation, and yet within certain limits their adjustments to life were so made that they were not unduly dependent. Their compensatory reactions in many respects counterbalanced their dependence.

In their independent achievements Helen Keller deserves, as might be expected, a much higher rating than Laura Bridgman. Not only are her social qualifications of a much higher order, but she has achieved distinction as an authoress, as a lecturer and as a thinker.

Laura Bridgman's accomplishments were of a far simpler order. They were outstanding in her day as representing the first notable instance of this kind. Helen Keller has developed a mode of speech and vocal expression which Laura Bridgman never acquired. Miss Keller is capable of conversing, and her conversation, although lacking in inflection, is thoroughly intelligible. At the most, Laura Bridgman was capable of fifty or sixty vocal sounds, few of which were recognizable words in any language although they all had definite connotation understood by her intimates.

Miss Keller is able to carry on conversation by listening to the speech of another. In doing so, she applies her fingers to the larynx, lips and nose. Laura Bridgman never possessed this accomplishment. Both of them, however, developed a high degree of manual dexterity; both were able to read with the fingers; both were able to write, and both were able to sew. In the latter respect Miss Bridgman excelled Miss Keller, who, however, has learned to use the typewriter with proficiency. If there is any difference in manual dexterity between them, it slightly favors Helen Keller.

THE DEVELOPMENT AND UTILIZATION OF THE SENSES

Only a brief comparative summary of the degree to which the several senses were developed and utilized is necessary to indicate the striking similarity between these two women.

In the sense of smell, Helen Keller had a supreme advantage. Laura Bridgman was almost wholly defective in this regard. The postmortem examination of her nasal cavity showed that she had suffered from a severe inflammation of the nasopharynx, after which she was totally devoid of the sense of smell for eight years. The nasal mucosa was generally diseased. She had a severe nasal catarrh which lasted all her life. The ethmoid bone and the mucous membrane covering it were seriously diseased in consequence of the inflammation. This was most particularly so on the left side. After her fifteenth year, she had slight olfactory perception.

Both of the women were blind. Helen Keller possesses no retinas and probably has no visual images. The latter fact together with her pronounced lack of sense of direction are to be made the subject of further studies. Laura Bridgman was totally blind most of her life. She had some degree of visual imagery and up to her eighth year had a feeble light perception in one eye. She possessed a most remarkable sense of direction. In this connection, it should be noted that in Laura Bridgman neither eye was removed and she retained both retinas, which, however, were insensitive to visual impressions throughout most of her life. Both upper eyelids were sunken. There was a distinct lack in the amount of orbital fatty tissue. Both eyeballs were small and indicated the presence of a prolonged severe inflammation. The right eye, about one-half the normal size, was wholly enclosed by the sclerotic coat except for a small central area 2 mm. in diameter, in which the cornea was represented by less opaque tissue. The left eyeball was larger than the right. The cornea was altered and opaque and consisted of a small area, 4 mm. in the horizontal and 2 mm. in the vertical. The eyelids were always closed. In a test of the sensitiveness of the eyes, light directed from a heliostat did not produce light perception but caused pain when concentrated. No effect was produced by gentle pressure or electric stimulation of the eyeballs.

The sense of taste in Miss Keller is little impaired, while that in Miss Bridgman was generally defective.

The sense of hearing was totally absent as such, both in Miss Keller and in Miss Bridgman. The pathologic report of Miss Bridgman's ears shows that the tympanic membrane was almost entirely destroyed and that the malleus and incus had entirely disappeared.

Laura seems to have had a certain superiority, particularly in two-point touch, although I have questioned this advantage over Helen Keller in the technical discussion of it earlier in the paper.

In temperature sense, pressure sense and electricity sense, Laura Bridgman was said to be below the average, while in these respects Helen Keller corresponded quite accurately with the normal.

In the vibratory sense both developed acute sensory powers, but there is certainly nothing to indicate any special development of the receptive ability in either of them. Such was certainly not the case in Helen Keller, who corresponded closely to the normal. It was probably not true of Laura Bridgman.

The postural and motion sense in Helen Keller was about equivalent to that of the average normal adult, and judging from the history of Laura Bridgmen, the same was probably also the case with her.

The balance sense appears to have been well preserved and corresponds closely with the normal in both.

In comparison with normal adults, Helen Keller and Laura Bridgman both illustrate the same points, namely, that the peripheral receptors of the general sensory apparatus do not exhibit any compensatory development in those deprived in infancy of the special senses of sight and hearing. The fundamental organization of those senses which remained intact in Laura Bridgman and Helen Keller has no advantages over that of the normal adult. The primary sensory mechanisms were no more efficient than in the average, yet if ratings of comparative intelligence were made of Laura Bridgman and Helen Keller with the average run of mankind, it is unquestionably true that these two women would stand much higher in the scale than this average. If such an average were taken of any general community of civilized society including all walks of life, both educated and uneducated (but not defectives), there can be little doubt that both of these women would stand high in the figures of this average. If they were compared to those who have benefited by education, through high school grades, Laura Bridgman might in certain respects show intellectual inferiorities, but her advantages in other regards would probably offset this.

Helen Keller would stand, of course, far above such a rating. In fact, if she were compared with those who have enjoyed a full college education, there is no question that her rating would far surpass the average of those trained in this way. Indeed, it is my opinion that there are few intellectual men and women living today who could develop a higher intelligence quotient than Helen Keller, with properly adjusted tests. There are many features in her intellectual development which might justify her inclusion in the class of genius.

The comparative efficiency of these two women clearly indicates that they stand well above the rank and file of the human race. This fact is important since Laura Bridgman and Helen Keller are largely dependent on a single sensory area of the brain for their intellectual rating. This area is the parietal lobe which administers the functions of general body sense as typified by the sense of touch. All other sensory areas in the brain, except those for the sense of smell and taste as specified, are inactive. It thus seems justifiable to infer that the parietal area for general body sensation must have reached a high degree of development in these two special cases. Laura Bridgman and Helen Keller, with a small portion of their brains in active commission, have made an intellectual and social adjustment to life which, at the very least, is equal to the average. This must mean that the average brain with all of its parts working develops only a small fraction of its potential power. Such a conclusion is important in the light of the known amplifications of association which take place in the frontal lobe when all of the senses are contributing their complements of sensory synthesis to the mental life of the person. My figures as applied to the case of Laura Bridgman would seem to show that only about 25 per cent of the brain's actual power is developed by the average of the race. This fraction is in the broadest sense a working estimate only. Whatever the exact fraction is, this much may be said: If for the present it is a matter of reproach, it may for the future be a sign of promise.

Sir Arthur Keith believes that mankind has as yet developed scarcely more than one half of its possible brain power. Critical observation and study of the race as a whole must justify the general correctness of this low estimate. The facts here presented seem to indicate that man already has the mechanisms for a more adequate adjustment to life. He does not need any additions to his present equipment except the determination to develop its capacity by his own unaided efforts. The social and intellectual distinctions existing among men depend not on differences in the fundamental pathways of the senses, but on the ability which the brain acquires to elaborate the impressions received by these pathways. It is the associational expansions within the brain which account for the degree of its power. In explanation of Miss Keller, Miss Bridgman and others with similar cases, it may be urged that their achievements are the result of compensation, and that unless an imperative demand for such compensation exists, no such expansion ever occurs. Many organic structures are endowed with compensatory capacities which develop under the stress of need. That need may be a sudden emergency, a sudden privation, or it may be a slow and persistent demand calling on the latent powers of a structure which would otherwise remain below its highest efficiency. This is true of the muscular system in athletes. It is also true of the excretory system in certain kinds of poisoning, or of the cardiovascular system and the respiratory system in many diseases. It is equally true of the brain as attested by facts pertaining to specialization and intellectual training.

To maintain that expansion in the powers of this organ apparent in the special cases here discussed is compensatory affirms that the brain is capable of further development. It is not necessary to rely solely on theory to uphold this postulate. The brain of Laura Bridgman is available for tests of its validity. This brain was carefully studied by Dr. Henry H. Donaldson and supplies many important facts bearing on the problem in question. Laura Bridgman's brain was removed eight hours after death. Its volume was calculated by Dr. Donaldson as 1,178 cc. and its weight, 1,204 Gm. All of the cranial nerves were identified except the spinal accessory nerve. The brain stem, including the medulla, pons and cerebellum, was normal. The superior and inferior colliculi were flattened and small, as was also the pulvinar. All were much smaller than in the normal brain. These structures illustrate clearly the organic response to functional demand. Being blind and deaf, Miss Bridgman made no demand on the primary receiving centers of the functions of sight and hearing. In consequence, they showed little of their normal and proper development. The cerebral hemispheres also revealed developmental failures of the same general character. The defects here were conspicuous in those areas of the brain on which little functional demand was made. Thus, the occipital lobes were small and flattened, apparently in direct proportion to their lack of function in visual capacity. The temporal lobes were also small, and all of the fissures in them were wide, indicating a low degree of convolutional development. This smallness and imperfect growth are significant in connection with the fact that Miss Bridgman was deaf. The insula (island of Reil) was much more exposed than in the normal brain, being more exposed on the left than on the right side. Its exposed area on the left was 128 square mm., and on the right, 40 square mm., a proportion of 3 : 1. In the normal brain the island of Reil is entirely concealed. Broca's area shows some defect which is significant, since Laura Bridgman was right-handed. The cuneus of the occipital lobe was small on both sides, but the left was smaller than the right. This deficiency has a peculiar significance in view of the fact that Laura Bridgman had light perception in the left eye until she was 8 years old.

TABLE 11.—*Comparison of Frontal Lobes of Laura Bridgman, an Insane Person and a Normal Adult*

	Right, per Cent	Left, per Cent	Total Average, per Cent
Laura Bridgman	36.8	39.9	38.3
Insane woman	40.0	41.0	39.5
Normal adult	38.3	40.9	39.6

The parietal lobe was well developed, in response to touch sensation, particularly for the hand and face.

Measurements of the surface of the frontal lobe show that in this region Laura Bridgman was somewhat below the average. Table 11, a comparison made between Miss Bridgman, an insane woman and a normal adult, shows the relation of the right and the left frontal lobes to the entire surface of the brain, in percentages.

The difference appears to be due to the smaller average in the depth of the sulci in the frontal lobe.

The total area of Laura Bridgman's cortical surface was as follows: right, 98,946.5 sq. mm.; left, 101,256 sq. mm.; total, 200,202.5 sq. mm. This is somewhat below that of the average normal woman.

In the matter of cortical thickness, the Bridgman brain showed certain departures from the normal. The average normal thickness of the cortex varies from 2.24 to 2.91 mm. The average of nine normal brains (all areas) was 2.92 mm. The average of Laura Bridgman's brain (all areas) was 2.59 mm. Not only in its thickness but also in its cell richness the cortex of the Bridgman brain showed differences as compared with the normal. In general, the large cortical cells were smaller and fewer in number than in normal brains. Laura Bridgman's brain showed cellular defects in the visual, olfactory and taste areas. Her cortex was 89 per cent as thick as the normal.

The sensory area for general body sense was normal. The speech cortex was not particularly thin. The speech area neurons, although somewhat small, did not show remarkable departures from the normal. Perhaps the fact that the speech area (Broca's area) in Laura Bridgman was so nearly intact in a dumb person may seem surprising. Laura Bridgman made use of fifty or sixty different sounds. The only words she ever used intelligently were "doctor," "see" and "ship." But there are many indications that she followed gestures made with her hands by movements of her lips and tongue, so that the relation between the gesturing motor centers for the limbs and the gesturing motor centers for the lips, tongue and organs of speech generally is probably most intimate. This, in some sense at least, would explain why Laura Bridgman's speech area appeared to be so nearly intact.

Expansions of the brain in response to functional demand would seem to depend on some definite physical basis. It is probable that such expansions are not due in any great measure to a material increase in the cortical cells. The number of these cells is already determined in the late fetal stages. The further development of the brain depends rather on connections established between various nerve cells by means of nerve fibers. Many facts indicate that such connections are made only when called for by needed communications. One structural result of this functional call is the appearance of an insulating substance on the nerve fibers. This insulation provides a greater efficiency in the fibers as conductors of nerve impulses. The acquisition of this insulating substance is known as maturing, and the insulation itself is called myelin. This is a fatty compound of complex nature. In his study of Laura Bridgman's brain, Donaldson expressed the opinion that expansion of this organ during life is due to increased medullation, that is, increased deposit of myelin on the nerve fibers. If this is the case, and there are many reasons to believe that it is, the chief factor favoring the deposit of myelin seems to be the functional use of the several brain areas. When nerve fibers are continuously called on to convey impulses, they tend to acquire their insulating sheaths, that is, to become myelinized.

The degree of insulation in relation to the functional capacity of nerve conduction may be determined in several ways. It is possible to estimate the amount of myelin in the insulating sheaths and nerve fibers in the brain at different periods of mental development from infancy to maturity.

In the infant at birth the percentage of myelin in the brain is 35.75; at 8 days of age, 38.5; at 6 months, 43.9; at 2 years, 45; at 3 years, 48.7; at 36 years, 50.9, and at 68 years, 52.3.

These estimations show a progressive increase in the amount of myelin in the brain, which seems in direct proportion to the increase of mental powers. In new-born cats and dogs little if any myelin is present in the optic nerve, and as the eyes remain closed for a week or ten days, there is at that time no visual function in these lower mammals. The human fetus at seven months has hardly any myelin in the optic nerve, but an infant born prematurely at this time rapidly myelinizes this nerve. These facts indicate that myelin insulation is in direct proportion to functional demand. In this connection I will add certain observations from studies which I have made with Casamajor on the relation of myelinization to the development of behavior in animals. By this study, we were able to show that special tracts in the brain myelinize as special behavioral components make their appearance, at the different stages from birth to adult life. Different animals show a different degree of myelinization according to their functional capacity at birth. In the rat, there is no myelin in the brain. The animal is born, as it were, prematurely and almost its entire care depends on the mother. It does not nurse until the eighteenth hour after birth. The dog and the cat are both capable of approaching the mother, and have certain other behavioral components immediately after birth. In their nervous system, myelinization is meager at this time. The guinea-pig is born in an almost complete functional state. It sheds its milk teeth in utero, and on the second day forages for itself. Its entire brain shows almost complete myelinization at birth.

Such facts as these strongly suggest that the relation of myelinization to development of the brain is based on the functional demand for specific conduction. It is probable that the degree of myelin in the human brain varies greatly in different persons. In certain diseases and in feeblemindedness, it is distinctly low. On the other hand, the greatest brain efficiency seems to depend on the ultimate myelinization of the greatest number of association fibers within the brain.

The cases of Laura Bridgman and Helen Keller illustrate how a specific area of the brain may be expanded to make amends for deficiencies in many other areas. It is unfortunate that the myelin contained in the parietal lobe of Laura Bridgman's brain was not estimated, but this is a consideration which must be left for similar studies in the future.

It is, I believe, the concentrated and systematic application of attention which endows experience with its full richness in associational value. Such attention of course depends on continuous functional use of association fibers in the brain. Time and patience are necessary for the development of such attention. Forel has likened consciousness to a retina in which there is a floating macula of attention. The difficulty with most of us is that this macula of attention floats too widely and too much, with the consequence that insufficient time is allowed for the needed concentration on any object or situation. As a result, there is an actual dearth of associations connected with most of the factors in our experience. Judgment and reason and all of the higher faculties suffer in consequence because the associational surplus from which they may draw their higher development is extremely meager.

The case of Helen Keller demonstrates what a brain may do under the influence of concentrated, systematic attention. It shows the expansions in understanding and in knowledge which result when the brain is properly importuned to develop them. As she maintains, the principle of Helen Keller's development has been Practice! Practice! Practice! The question naturally arises whether this principle applies to any brain, and in particular to the brain of modern man. The answer apparently should be in the affirmative. There are relatively few brains which could not be made better and more efficient by pursuing the proper methods of development. Certain difficulties have arisen heretofore and still do arise as obstacles. They are not, however, in the brain's potential power to respond, but rather in the general lack of desire to make the necessary demands for such further development. Many observers are intensely pessimistic and doubt that the ascendant elements in the human race today will in this regard ever develop to a higher degree. Indeed, there are some reasons to believe that mentally the human race as a whole is retrograding. If one views modern man in the broad sense as all that part of the race which has existed during the historic period, it would seem in some respects that our mental capacities are inferior to those of the Greeks, probably to those of the Romans, and it may even be to those of the Egyptians. So that concerning the historic period, if any statement seems justified at all, it is that mankind has stood still intellectually. The outright pessimist will say that it has gone backward. Nor is there now apparent any reassuring prospect that the essential physiologic process (application, patience, practice) on which further development of the brain depends will have its full opportunity. The day in which we live is characterized by a predominant spirit of haste. Most of our ideals are shot through by aspirations for speed. In consequence, insufficient time is allowed for that patience, that concentration and that systematic practice which are the prerequisites of further brain development. We find ourselves in the midst of many and multiplying distractions. The rapid influx of new contrivances deceives us into believing that we are developing new ideas. With the exception of many luxuries and labor saving devices, we lead about the same lives as did men 300,000 years ago. Human behavior and human relations are changed but little, certainly not enough to preclude those ancient repetitious cycles of maladjustment which have led from one war to the next, from one revolution to another, which have frustrated our best civic intentions and efforts and which have left us little, if any, better off morally or intellectually than our predecessors in the early days of human history.

Yet, brain development, like all other development, follows the laws of evolution. Into this evolutionary process during the past half century, there has come a new element. This factor has not operated heretofore, and the presence of it as a decisive influence may have far-reaching consequences. Intelligent men and women have come to recognize that there is such a thing as evolution. Being conscious of this fact they may, and undoubtedly will, direct their attention increasingly to its processes and to the nature of its underlying causes. What discoveries will be brought to light as a result of such efforts cannot be predicated. Much may properly be expected of it both to increase the understanding of our own mechanisms and to improve their capacities.

Another encouraging influence is found in the developmental history of man's brain. From my studies of the prehistoric human brain I was led to conclude that, beginning perhaps a million years ago with the ape-man (Pithecanthropus) and coming to modern man, the brain has shown a steady progressive development. Thus there is reason to believe that the brain of man today represents some intermediate stage in the ultimate development of this master organ of life. As a race, we appear to have developed but a fraction of its power. The greatest problem before us, therefore, is how to make a still better use of the brain. This problem may be solved only by the development of that comprehensive science which will eventually supply an adequate knowledge of all the mechanisms underlying the control of human behavior.

ABSTRACT OF DISCUSSION

Dr. S. E. **Jelliffe**, New York: Dr. Tilney said, and showed by a number of figures, that the tests of Helen Keller and the average normal, as he called it, were about the same. I seriously doubt that the quality of the tests or the nature of the tests that have thus far been devised are of any particular value. I am emboldened to make this statement more or less when I commence to consider some of the studies in eidetics made by Jaensch of Marburg, in which the value of the synesthesiae that Dr. Tilney has already made reference to are brought out. Helen Keller showed remarkable values in associating—I do not recall the details of her associations, but the associations between smell and sight and color and form and shape and feeling, etc., are really astounding. The students of eidetic phenomena have developed just this type of testing, and it is an extremely interesting corroboration of what Dr. Tilney has pointed out, namely, the persistence or the capacity for further elaboration of the olfactory eidetic phenomena in this particular patient who has been so carefully studied. And what is true of olfactory eidetic phenomena—eidetic meaning "image"—is true, as shown amply, for other types of sensory areas. Through this particular method of investigation, elaborated by Jaensch, it seems to me we have a far greater discriminative type of testing than those which we as objective neurologists have as yet devised.